Thoracolumbar spinal fractures

Leferink, Vincentius Johannes Maria

Chapter 1

General introduction

History

The first written proof of treatment of spinal fractures was found in the Smith papyrus rolls originating about 1550 years before Christ. Highly specialised doctor-priests took care of the patients with spinal fractures. They performed wound treatment, put on bandages and subscribed rest in the horizontal position [30]. In these days probably only open fractures and fractures with considerable kyphotic deformity were recognized. Hippocrates distinguished spinal fractures with and without neurological deficit. Patients with paralysis would die. Spinal fractures without paralysis were treated by distraction, *manual* reduction, and rest in supine position [30]. Special tables were designed and used for these treatments by Hippocrates and Oribasius (Fig.1 and Fig.2) [38].

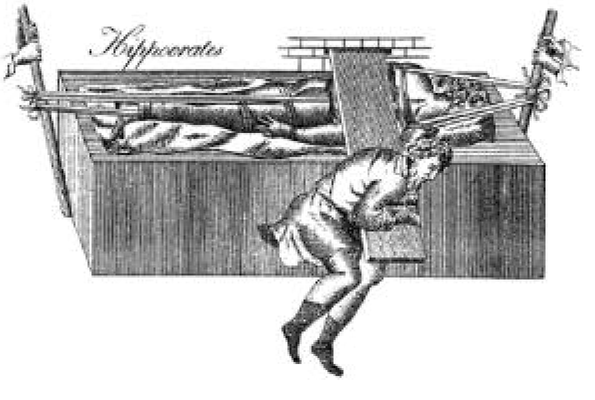


Fig.1 Reduction table used in non operative treatment of spinal fractures and dislocations by Hippocrates [38]

Even some kinds of operative treatments were described, but it is uncertain whether those operations actually were performed. Laminectomy and removal of the narrowing fracture part in case of paralysis was suggested as soon as the 7th century by Paul of Aegina. However, the statement of John Bell: *The cutting into a fractured vertebra is a dream* (1799), probably provides a better idea of the possibilities in the middle ages. Conservative treatment was the golden standard for a long time. Malgaigne (1847) and Böhler (1932) advocated indirect manipulative anatomical reduction by longitudinal traction and hyperlordosis, immobilisation in a plaster jacket, followed by intensive muscle training (physiotherapeutics *avant la lettre*) [30].

Fig.2 Table used for nonoperative treatment by Oribasius [38]

Nicoll advised a completely functional treatment after he evaluated the treatment of miners with spinal fractures. The anatomical result of the treatment was rather poor, but Nicoll stated that most of the miners had perfect results, because they could perform the heavy mining job, showing … *their ability to withstand the conditions of stress that arise in working at the coal-face in cramped positions … without discomfort* [31].

One should realise that the first radiographs of the spinal column were only available since 1925, because much higher voltages were needed for trunk radiographs than for extremity radiographs. All earlier remarks about fractures, dislocations and reduction have to be considered reflections of gross distortions of the normal anatomy or findings in post mortal dissection (Fig.3).

The history of spinal fracture treatment is described in a concise way by Memmert in *Die Wirbelsäule in der Anschauung* [30]. Most of the described history is derived from this book, unless other references are mentioned.
After 1970 improvements in (radio-)diagnostics, safer anesthesiological techniques, improved intensive care and development of more reliable implants were the prerequisites for further development of operative techniques.

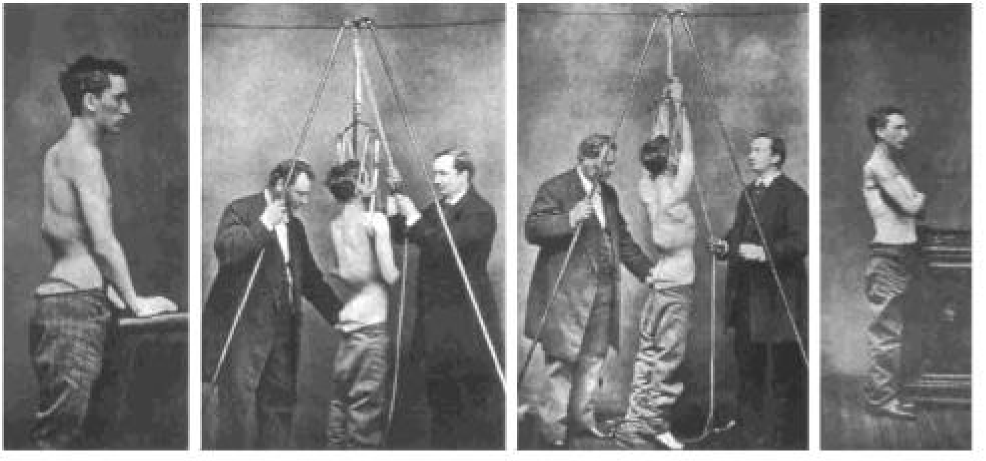


Fig.3 Gross distortions of the normal anatomy

Operative treatment of spinal fractures
Like in other fields in traumatology stable fixation of fractures and early movement was advocated in spinal fractures since 1960. The idea was that most of the compression type fractures (burst fractures) of the thoracolumbar transition could either be treated by a ventral fusion operation or by a dorsal transpedicular operation.

Fig.4 Harrington rod with laminar hooks

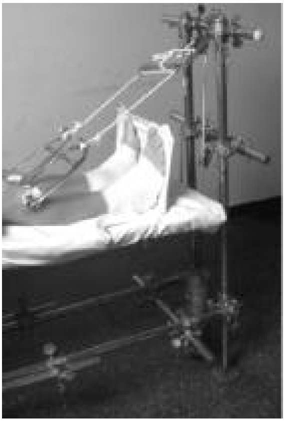
With retroperitoneal, transthoracic or transperitoneal access a direct ventral reduction and reconstruction with plate osteosynthesis was performed.
In the dorsal procedure fracture reduction was achieved by antikyphosing and dorsal compression. This indirect reduction was completed by ways of stabilization known from scoliosis treatment. Both procedures were frequently combined with decompression corporectomy or laminectomy. A positive effect of these additional procedures could never be proved [2]. After the application of dorsal long segment fixation (5 segments) with Weiss springs, Roy-Camille plates, Harrington rods (Fig.4), or with other implants used in scoliosis treatment, shorter segment fixation systems were developed to treat spinal fractures: the external fixator (Magerl) and internal fixators (Dick, Olerud) [12;22;27;32;40;57]. Also new anterior systems were developed: Kostuik, Dunn, Kaneda [10;14;23] and many other implants.

History of treatment of spinal fractures in the University Hospital Groningen

Harrington rods

Operative treatment including surgical stabilization with Harrington's instruments was practised in the University Hospital Groningen between 1979 and 1987 [6;12]. The impact of this treatment on the anatomy was evaluated radiologically (plain radiographs and conventional tomography) and the findings are described in the thesis of one of the co-authors of several chapters of this thesis [51]. In those days preoperative halobitibial traction was used for reduction in patients with spinal fractures (Fig.5).

5a



5b

Fig.5 Halobitibial traction preceded operative treatment (5a halo; 5b bitibial pins)

In more than 80 percent of the operatively treated patients halobititibial traction preceded operative treatment. The mean duration of the traction was 15 days. The complications associated with halobititibial traction and the operative procedure were numerous. Halobititibial traction was frequently associated with pin tract infection at the tibia (10 percent). In two out of 49 patients the traction had to be discontinued for psychological reasons. One of these patients was psychiatrically treated before.
Reported complications related to the operative treatment with Harrington rods were infection, implant failure or hook dislocation, bleeding and hyperpathy of the lower dermatomes (cumulative percentage of complications 20 percent) [51].

Internal fixation according to Dick [8]
The "fixateur interne" was presented in 1987 as a new device for posterior spinal fracture surgery. This device was derived from the Magerl external short segment spinal fixator [27]. It consists of four long Schanz screws, which are inserted from a posterior approach through the pedicles into the adjacent vertebral bodies, and of two connecting threaded longitudinal rods, carrying mobile clamps that can be fixed in the right position by nuts (Fig.6). The long lever arms of the Schanz screws enable manual reduction (Fig.7). The lever arms are shortened with a steel cutter at the end of the operation (Fig.8).

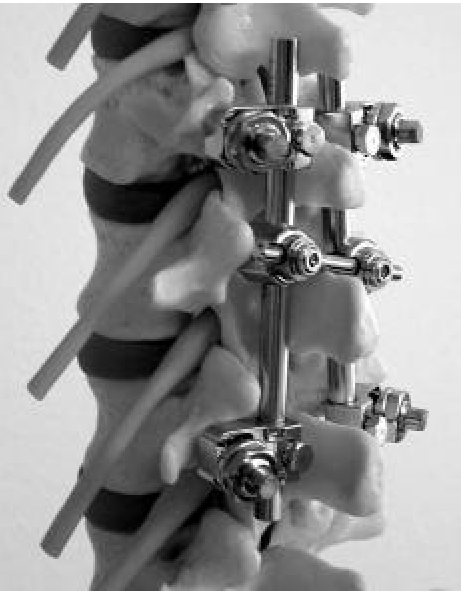


Fig.6 Dick’s internal fixator in model

As the device is stable against flexion and rotation by itself, the fixation can be restricted to the immediately adjacent vertebral bodies of a lesion, leaving the rest of the spine mobile. In fracture treatment the instrumentation is combined with a direct repair of the anterior loss of bone stock by a transpedicular bone grafting procedure from the same dorsal approach [5]. Instead of the unilateral transpedicular cancellous bone graft, as advocated by Daniaux, we have performed a bilateral cancellous bone graft in order to deposit as much bone in the reduced vertebral body as possible.
A dorsolateral spondylodesis was done with the rest of the cancellous bone graft at the level of destructed endplates; for example the upper segment in incomplete burst fractures, and both segments in complete burst fractures. A standard treatment and follow up protocol was used. Only minor changes in treatment were allowed. Therefore the treatment of patients in 1988 was very similar to the treatment in 1997.

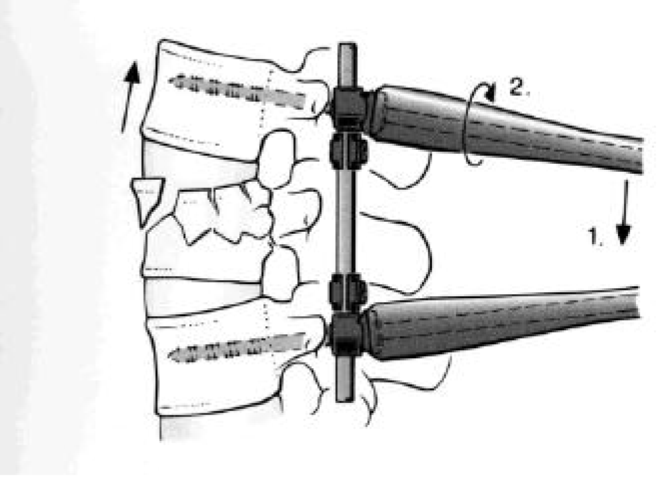


Fig.7 Acting mechanism and applied antikyphosing forces (1) in the internal fixator. Fixation of nut with the same instrument (2)

In February 1996, in our hospital the Dick fixator was replaced by the stainless steel Universal Spinal System (USS) derived from the Dick system. Since 1998, titanium USS-implants are used.

Fig.8 Universal Spine System USS (titanium) with shortened Schanz screws

Since 1988 over 350 patients with a spinal fracture of the thoracolumbar junction have been operated according to this system in our hospital. All three implant systems act according to the same principles (Fig.7).

Rehabilitation and follow up

Much attention has to be paid to correct rehabilitation and psychological support. In our hospital the intensive collaboration with the colleagues in the nearby rehabilitation centre Beatrixoord has proved to be very valuable. In the postoperative period, the patients were treated by physical therapy in bed during two weeks. Afterwards they were mobilised in a simple thoracolumbar reclination orthesis until nine months after the operation (Fig.9).

At nine months the hardware was removed. Afterwards the temporarily fixed segment has the opportunity to regain its mobility. If the spondylodesis was bridging the same levels as the internal fixator no hardware removal was done. All patients and their radiographs were examined at regular intervals (at 3, 6, 9, 12 and 24 months).

Epidemiology

Descriptives and epidemiological changes in the period 1970-1999

The group of operatively treated patients in this study forms only a small part of all patients with spinal fractures admitted to our hospital. Most patients with thoracolumbar spinal fractures are treated conservatively.

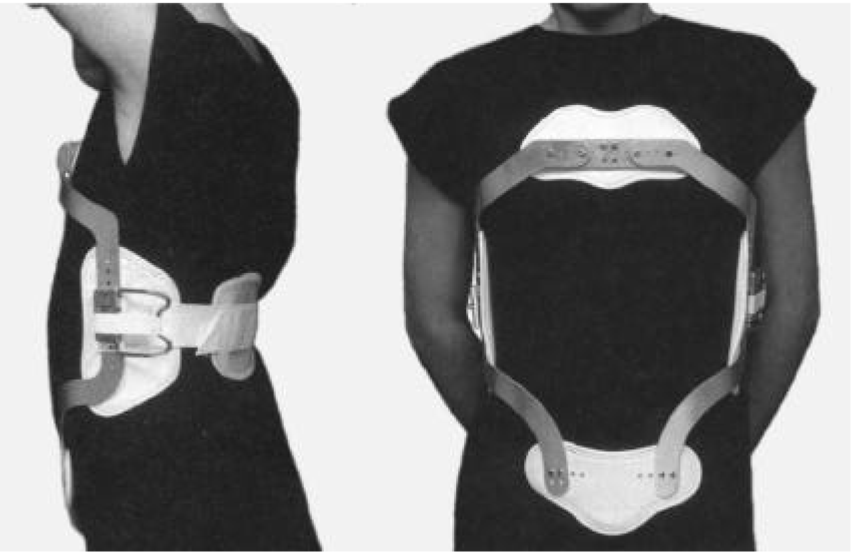


Fig.9 Thoracolumbar orthesis

Comprehensive epidemiological data of trauma patients with spinal fractures are scarce [4]. Many epidemiological reports about spinal fractures focus on osteoporosis as an etiologic factor [3;15]. Studies concerning only operatively treated patients with spinal fractures show selective and biased data that might be useful for capacity planning in hospitals or evaluating results of operative treatment, but not for epidemiological purposes [21;24]. Epidemiological evaluation of subgroups like pediatric cervical spine injuries, spinal fractures in aviators, sports-related spinal injuries give important information, but only about these subgroups, for example in the field of risk evaluation or specific aftertreatment [1;16;37;41].
In our hospital 10.000 new trauma patients are treated each year. The yearly number of patients has been relatively constant in the last three decades. About 200 polytrauma patients (ISS$\geq$16) are submitted to the emergency trauma unit of our hospital, and 50-70 more are transferred after initial treatment in other hospitals. The adherence area of our hospital for polytrauma patients, acetabular fractures and spinal fractures amounts to about 2 million people.

RLOG

Hospital registries of all primary visits of trauma patients like RLOG (Registratie van Letsels en Ongevallen Groningen/Registration of traumatic lesions and accidents Groningen) showed to be relevant in supplying the data to analyse non-

fatal injuries [33]. Since 1970 the data of more than 300,000 trauma patients have been included in the RLOG database.
The RLOG data survey revealed a slight increase in numbers of patients with spinal fractures during the last three decades (Fig.10).
The most frequently diagnosed single spinal fracture is the thoracolumbar fracture without neurological deficit (Table 1 and Table 2). The high prevalence rates in 20-29 years old men represent the young male peak in general in epidemiological studies in traumatology [17].
In patients with spinal fractures of the thoracolumbar transition the observed male/female ratio is 2.5 at age 20-29 and shows inversion at the age of 60. This inversion probably is the result of more pronounced osteoporosis in women as well as their higher life expectancy.
All our patients are registered in the trauma registry RLOG according to the International Classification of Disease, version 8, later version 9 (ICD-8 and ICD-9).

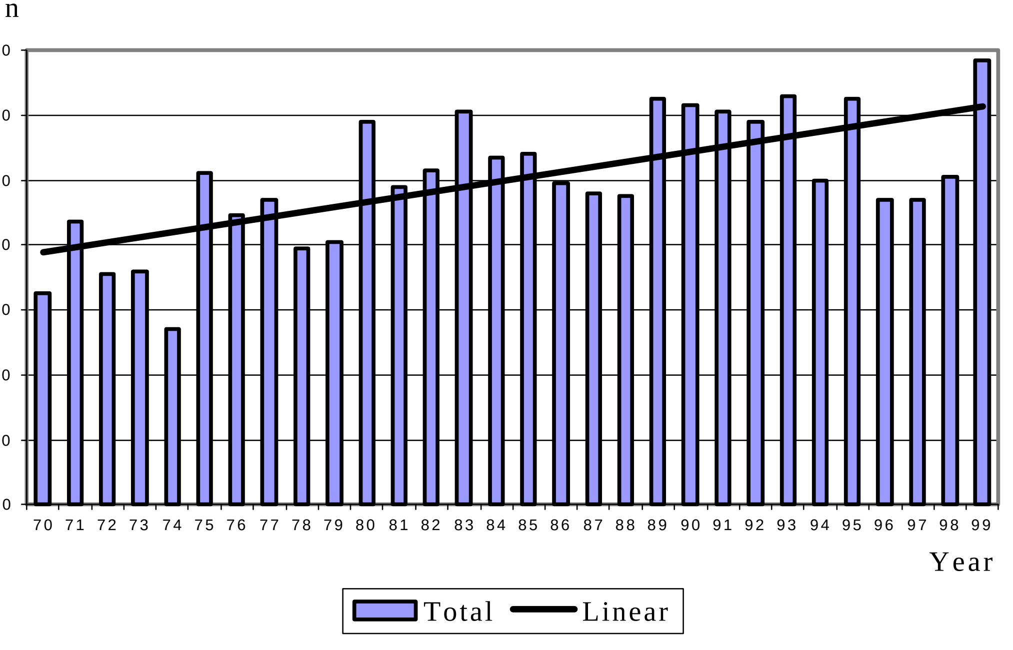


Fig.10 Number of patients per year with spinal fractures treated in the University Hospital Groningen between 1970 and 1999 (n=3003) and the linear trend in 30 years

Table 1 Number of patients, with monolevel (single) spinal fractures, divided according to level, age-group, gender, and neurological deficit in the period 1970 to 1999 (n=2713) *without neurological deficit, ** with neurological deficit

Age	0 - 9		10 - 19		20 - 29		30 - 39		40 – 49		50 - 59		60 - 69		70 - 79		80 - 89		>90		Total	
Level	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
Cervical*	6	1	38	21	100	21	57	20	45	20	25	12	26	16	10	12	12	5	4	0	323	128
Th.lumb*	11	9	114	74	262	107	192	76	139	86	130	98	86	94	58	103	17	49	1	9	1010	705
Sacral*	2	1	10	7	39	22	15	20	29	14	11	10	3	7	5	10	2	6	0	1	116	98
Cervical**	2	1	23	3	24	3	18	7	4	7	9	5	7	5	6	1	2	2	1	0	96	34
Th.lumb**	0	1	12	1	29	7	23	6	11	5	16	4	5	5	5	4	4	1	0	1	105	35
Sacral**	0	0	6	6	8	15	4	8	5	4	1	4	0	2	0	0	0	0	0	0	24	39
Total	21	13	203	112	462	175	309	137	233	136	192	133	127	129	84	130	37	63	6	11	1674	1039

Table 2 Causes of accident in patients with (single) spinal fractures, with and without neurological deficit

	Spinal fracture without neurological deficit			Spinal fracture with neurological deficit			
E-code Level Cause	Cervical	Thoraco Lumbar	Sacral	Cervical	Thoraco lumbar	Sacral	Total
Private	106	765	93	49	53	32	1098
Sports	24	109	7	4	12	3	159
Violence	4	12	4	0	1	3	24
Traffic	112	293	53	29	25	4	516
Work	2	59	6	4	5	1	77
Self inflicted	4	61	6	3	9	1	84
Unknown	199	416	45	41	35	19	755
Total	451	1715	214	130	140	63	2713

The causes of accident, as registered in the RLOG as E-codes of the ICD, show that most accidents leading to spinal fractures occur in the private environment (Table 2). This includes fall from a height and hit by falling object. Traffic accidents are an important cause as well (Table 2).
The percentage of patients with neurological deficit is 22 in the cervical and sacral group, but only 8 in the thoracolumbar group (Table 2).
ICD-codes revealed Abbreviated Injury Scale (AIS) scores and these were cumulated to ISS in case of multiple injuries [18]. ISS calculation was performed by means of a Pascal computer program in all patients [18]. The Injury Severity

Score (ISS) in monotrauma patients with spinal fractures can only be 4, 9, 16, or 25. Lesions to other AIS-body regions and multiple spinal fractures can result in higher (cumulative) ISS-scores, but also in scores between the above mentioned scores.

Table 3 ISS and number of patients with monolevel (mono) or multilevel (multiple) spinal fractures, with or without other injuries (n=3003)

ISS	Spinal fractures		Spinal fractures and other injuries		n
	Mono	Multiple	Mono	Multiple	
4	178	4	76	1	259
5	0	0	53	1	54
6	0	0	18	2	20
8	0	0	57	4	61
9	926	39	101	2	1068
10	0	0	131	5	136
11	0	0	30	1	31
12	0	0	22	0	22
13	0	15	281	27	323
14	0	0	70	12	82
16	75	4	27	1	107
17	0	0	118	11	129
18	0	35	79	14	128
19	0	0	23	7	30
20	0	0	34	3	37
21	0	0	6	1	7
22	0	1	106	39	146
24	0	0	14	1	15
25	1	5	37	5	48
26	0	0	4	0	4
27	0	0	55	18	73
29	0	0	40	10	50
30-39	0	0	29	11	40
40-49	0	0	4	1	5
50-75	0	0	0	1	1
Unknown	53	0	65	9	127
Total	1233	103	1480	187	3003

The mean ISS did not change in the studied period (ISS 12), but the percentage of patients that is treated in the outpatient clinic only increased from 60% to more than 70%. Of all spinal fracture patients in 30 years 27.3 percent had an ISS ≥16 (Table 3).

Diagnostics, classification and indications for operative treatment

Diagnostics

The mechanism and the impact of the trauma, in combination with the complaints of the patient generally give rise to the suspicion of a spinal fracture. Mechanisms are fall or jump from a height, deceleration trauma and direct blow, for example in traffic accidents or sports, but also in the working or private environment. The probability of fractures in minor trauma increases in pathological conditions of the spinal column.

Acute back pain, mild or severe, and, in a minority of patients, sensory or motor loss, wounds of the back, or palpable deformities or gaps, add to the suspicion. Plain radiographs of the thoracic spine and the lumbar spine in two directions are the initial forms of imaging for the vast majority of patients. These radiographs are more helpful in proving the existence of a spinal fracture than in excluding it. Special attention should be given to the thoracolumbar junction. Often extra radiographs have to be made of this junction to avoid misinterpretation of lesions at the edge of the beam. Before the early nineties conventional tomography was performed to assess stability and to classify the fracture [28]. Since the eighties computer tomography, including digital sagittal reconstructions, gradually replaced the conventional tomography.

Classification

A classification should provide, in a descriptive and concise way, information about the severity of the lesion and should give an identification of any lesion by means of a (rather) simple algorithm. In daily use it should give guidance to the form of treatment in relation to prognosis.

After classifications of Nicoll [31], Holdsworth [13], Whitesides [58], Louis [25], and Roy-Camille [39] the three column classification of Denis was widely accepted [7]. Further developments by McAfee [29], Ferguson and Allen [11], influenced by the increasing possibilities of CT, lead to the comprehensive classification of Magerl et al [26].

This classification is based on the pathomorphological characteristics of the injury. Three (supposed) mechanisms of injury, of which the effect is shown in the radiographs and CT scans, give name to the three main categories: A=compression, B=distraction and C=rotation type fractures. In each group morphological criteria lead to further classification in (three) subgroups, et cetera (Table 4).

Table 4 Comprehensive Classification, groups and subgroups

A Compression injury	A1 Impaction fracture	A1.1 Endplate impaction
		A1.2 Wedge impaction
		A1.3 Vertebral body collapse
	A2 Split fracture	A2.1 Sagittal split fracture
		A2.2 Coronal split fracture
		A2.3 Pincer fracture
	A3 Burst fracture	A3.1 Incomplete burst fracture
		A3.2 Burst-split fracture
		A3.3 Complete burst fracture
B Distraction injury	B1 Posterior ligamentary lesion	B1.1 With disc disruption
		B1.2 With type A fracture
	B2 Posterior osseous lesion	B2.1 Transverse bicolumn
		B2.2 With disc disruption
		B2.3 With type A fracture
	B3 Anterior disc rupture	B3.1 With subluxation
		B3.2 With spondylolysis
		B3.3 With posterior dislocation
C Rotation injury	C1 Type A with rotation	C1.1 Rotational wedge fracture
		C1.2 Rotational split fracture
		C1.3 Rotational burst fracture
	C2 Type B with rotation	C2.1 B1 lesion with rotation
		C2.2 B2 lesion with rotation
		C2.3 B3 lesion with rotation
	C3 Rotational shear injury	C3.1 Slice fracture
		C3.2 Oblique fracture

In general A type fractures are less severe than B type fractures, and B type fractures less severe than C type fractures (Fig.11). In the subgroups the lesions are ranked as well. For example: an incomplete burst fracture is classified as A3.1, but in case of additional dorsal ligament rupture (caused by distraction) as B1.2. Note that isolated spinal process or transverse process fractures are not included in the classification [26].
We started to use the Magerl (AO) classification in 1994 because it allows categorization of injuries to all relevant parts of the spine. In this study we

classified all fractures according to this classification, including the fractures of the patients treated between 1988 and 1994.

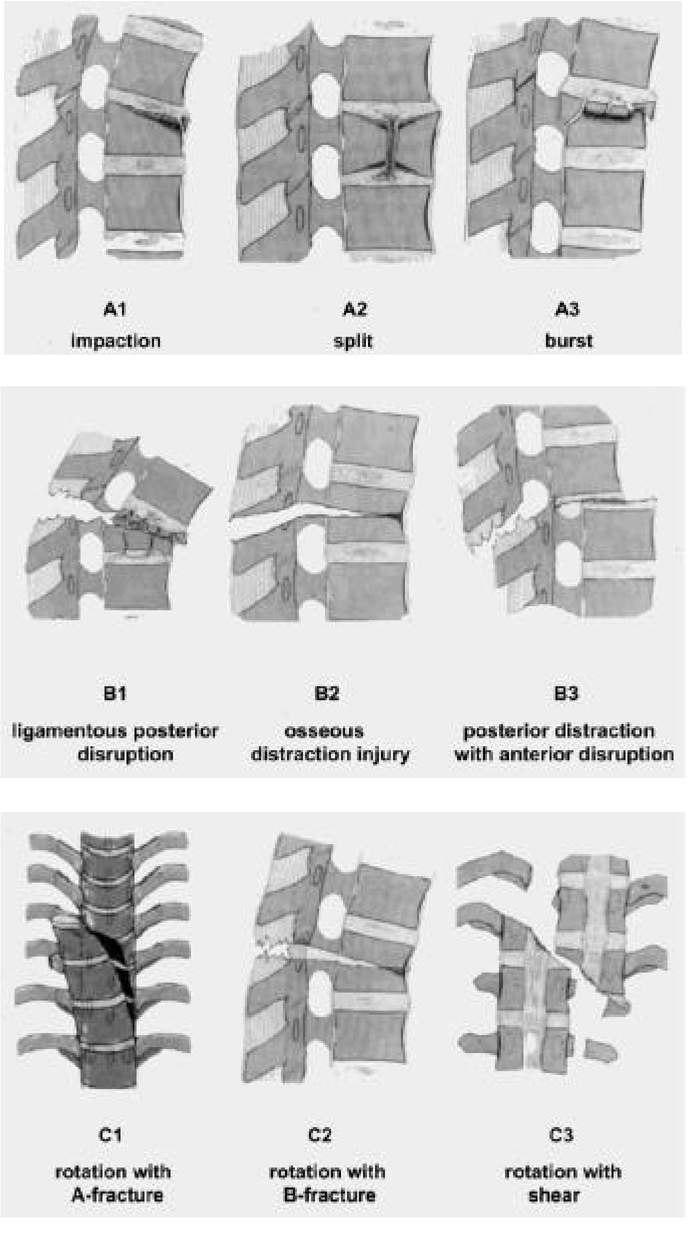


Fig.11 Comprehensive Classification: A type fractures (compression type), B type fractures (distraction type) and C type fractures (rotation type)

To our opinion, the classification scheme will have to be revised. Based on additional MRI information, it will be clear which kinds of soft-tissue injuries should be considered indicative of various types and subgroups [34-36].

Indications for operative treatment

In the last decade the following fracture types formed an indication for operative treatment: type A fractures (Fig.11): A1.2 fractures, only when the wedge angle of the body is more than 15 degrees, A2.3 fractures and A3 fractures (Table 4). B and C type fractures are usually operated, although in some cases there might be reasons to prescribe conservative treatment. Age, degree of dislocation of the fracture, medical history and other injuries are other important factors in decision making.

Outcome

Desperation when the neck or the back has broken is still a common reaction of the patient and his family. The public generally accepts that a spinal injury causes death or at least paralysis or paraplegia. Though Trickey stated in 1976 that spinal fractures should be treated in the same way as other fractures and dislocations and that nearly always there will be a complete recovery [42]. Many studies focus on the radiological outcome, but like in other fractures functional outcome does not necessarily correlate with the radiological result. The neurological sequelae strongly influence the functional outcome; however the treatment modality has only a marginal influence on the neurological outcome.

An important outcome study is the meta analysis of Dickman [9]. In his study the performance of four different groups of operative treatment was compared, i.e. pedicle screw fixation devices, hook-rod systems, Luque instrumentation, and anterior instrumentation devices. Journal articles between 1975 and 1993 were evaluated for sufficient clinical and radiographical outcome data. One hundred and sixty-eight articles on thoracolumbar fractures were studied of which 110 were rejected after review. Fifty-eight articles could be included in the meta-analysis. Fusion and residual pain were outcome measures. They were similar in different groups and seemed not to be the problem in either treatment. The complication rate was similar as well, up to 27 percent! The higher loss of fixation in hook-rod systems (9.5%) compared to fixation problems in pedicle screws (3.3%) was statistically significant. In a more recent study it seems that the dorsal approach is accompanied with less complications than the anterior approach (14.1% versus 29.7%) [19]. In our series of 183 operatively treated patients between 1988 and 1996 we did not observe any deep infection nor neurological complications, but we noticed three superficial infections after implant removal. One major complication occurred: intraoperatively a retractor hook was placed behind a rib and this caused an intrathoracal bleeding complication that at first was misdiagnosed. The patient died of haemorrhagic shock despite thoracotomy.

Influence of insurance and social security on the outcome
It is generally accepted that minor impairments may have major consequences in working ability and sports leisure. It is logical that this accounts for major impairments as well. In this respect the results of Nicoll concerning miners with conservatively treated spinal fractures and their return to work status can only be seen as an illustration of the consequences of injury and treatment in those days [31]. Even in huge multicentre studies like the study performed by the Working Group on Spine of the German Trauma Association it is very difficult to draw general conclusions about specific therapies, for example anterior and posterior techniques in relation to outcome and work status [20].
In the Netherlands it takes about a year before it will be clear whether a patient can return to work and about two years before the final assessment about definite inability to work and social security benefits can be made in severely or multiple injured patients [49].

The research history in the Department of Surgery/Traumatology of the University Hospital Groningen, concerning outcome in trauma and in thoracolumbar fractures facilitates the performance of research in this field. A thesis on the evaluation of the conventional radiological examination of thoracolumbar fractures was published in 1988 [28]. The formerly mentioned study on the results of the operative treatment of thoracolumbar fractures with Harrington rods was published in 1993 [51]. Many studies on the evaluation of short-term and long-term outcome in (major) trauma were published in collaboration with the Department of Rehabilitation [43-50]. Studies on the effects of deceleration trauma of the neck (whiplash) were published in collaboration with the Departments of Anaesthesiology and Psychology [52-56].

Outline of this thesis

Chapter 1 provides information about the history of spinal trauma and the conservative and operative treatments, about the epidemiology of the study populations in this thesis, diagnostic procedures, classifications, operative procedures, rehabilitation, and the follow up schemes, as applied to the patients described in this study.

With respect to the new developments in the field of diagnostics and classifications of spinal fractures the following questions will be answered in Chapter 2:

- What percentage of B type fractures are initially unrecognised and regarded as A type fractures?
- Which are characteristic radiological qualities of initially unrecognised B type fractures?

In the field of results of the operative treatment of spinal fractures we studied radiological data in order to answer the following questions in Chapter 3:

- Does the vertebral body collapse after removal of the implants, despite transpedicular bone grafting?
- Is correction of the regional angle maintained after surgery?
- And if not, does the loss of the intervertebral angle contribute to this change?
- What is the influence of implant failure on the radiological measurements?

The second set of questions concerning radiological results will be answered in Chapter 4:

- Are there any changes of the posterior segmental height (PSH) during operation and in the course of further treatment?
- Do the bony parts in the spinal canal in plain radiographs disappear in the course of treatment, and how many patients have developed a normal width of the spinal canal two years after the initial treatment?
- Are there changes of the midsagittal diameter of the spinal canal as measured in CT-slices?

The third set of questions about radiological outcome concerns the functional aspects of remaining mobility after operative treatment in Chapter 5:

- Does dorsal spondylodesis of one segment also cause loss of range of motion (ROM) at other segments or does it result in increased ROM at the surrounding segments?
- Does dorsal spondylodesis result in ankylosis of the affected intervertebral disc space?

Finally functional outcome tests and questionnaires try to reveal the answers to the following questions in Chapter 6:

- Which are the impairments in operatively treated patients with a thoracolumbar burst fracture?
- What is their ability to perform in activities of daily life?
- What is their return to work status and quality of life?

In the Chapters 7, 8, and 9 we summarize our findings in a general discussion focusing on the consequences for future management of spinal fractures. We point out ongoing and future research in the field of spinal fractures.

References

1. Belmont P-JJ, Taylor KF, Mason KT, Shawen SB, Polly D-WJ, Klemme WR (2001) Incidence, epidemiology, and occupational outcomes of thoracolumbar fractures among U.S. Army aviators. J Trauma 50:855-861

2. Boerger TO, Limb D, Dickson RA (2000) Does 'canal clearance' affect neurological outcome after thoracolumbar burst fractures? J Bone Joint Surg Br 82:629-635

3. Cooper C, Atkinson EJ, Kotowicz M, O'Fallon WM, Melton LJ (1992) Secular trends in the incidence of postmenopausal vertebral fractures. Calcif Tissue Int 51:100-104

4. Cooper C, Atkinson EJ, O'Fallon WM, Melton LJ (1992) Incidence of clinically diagnosed vertebral fractures: a population-based study in Rochester, Minnesota, 1985-1989. J Bone Miner Res 7:221-227

5. Daniaux H (1986) Transpedikuläre Reposition und Spongiosaplastik bei Wirbelkörperbrüchen der unteren Brust- und Lendenwirbelsäule. Unfallchirurg 89:197-213

6. Dekutoski MB, Conlan ES, Salciccioli GG (1993) Spinal mobility and deformity after Harrington rod stabilization and limited arthrodesis of thoracolumbar fractures. J Bone Joint Surg Am 75:168-176

7. Denis F (1983) The three column spine and its significance in the classification of acute thoracolumbar spinal injuries. Spine 8:817-831

8. Dick W (1987) The "fixateur interne" as a versatile implant for spine surgery. Spine 12:882-900

9. Dickman CA, Yahiro MA, Lu HT, Melkerson MN (1994) Surgical treatment alternatives for fixation of unstable fractures of the thoracic and lumbar spine. A meta-analysis. Spine 19:2266S-2273S

10. Dunn HK (1984) Anterior stabilization of thoracolumbar injuries. Clin Orthop 189:116-124

11. Ferguson RL, Allen-BL J (1984) A mechanistic classification of thoracolumbar spine fractures. Clin Orthop 189:77-88

12. Harrington PR (1988) The history and development of Harrington instrumentation. By Paul R. Harrington, 1973. Clin Orthop 227:3-5

13. Holdsworth FW (1963) Fractures, dislocations, and fracture-dislocations of the spine. J Bone Joint Surg Br 45:6-20

14. Kaneda K, Taneichi H, Abumi K, Hashimoto T, Satoh S, Fujiya M (1997) Anterior decompression and stabilization with the Kaneda device for thoracolumbar burst fractures associated with neurological deficits. J Bone Joint Surg Am 79:69-83

15. Kannus P, Niemi S, Palvanen M, Parkkari J (2000) Continuously increasing number and incidence of fall-induced, fracture-associated, spinal cord injuries in elderly persons. Arch Intern Med 160:2145-2149

16. Katoh S, Shingu H, Ikata T, Iwatsubo E (1996) Sports-related spinal cord injury in Japan (from the nationwide spinal cord injury registry between 1990 and 1992). Spinal Cord 34:416-421

17. Kingma J (1994) The young male peak in different categories of trauma victims. Percept Mot Skills 79:920-922

18. Kingma J, ten Vergert E, Werkman HA, ten Duis HJ, Klasen HJ (1994) A Turbo Pascal program to convert ICD-9CM coded injury diagnoses into injury severity scores: ICDTOAIS. Percept Mot Skills 78:915-936

19. Knop C, Bastian L, Lange U, Oeser M, Zdichavsky M, Blauth M (2002) Complications in surgical treatment of thoracolumbar injuries. Eur Spine J Springer link DOI 10.1007/s00586-001-0382-6

20. Knop C, Blauth M, Bühren V, Arand M, Egbers HJ, Hax PM, Nothwang J, Oestern HJ, Pizanis A, Roth R, Weckbach A, Wentzensen A (2001) Operative Behandlung von Verletzungen des thorakolumbalen Übergangs-Teil 3: Nachuntersuchung. Ergebnisse einer prospektiven multizentrischen Studie der Arbeitsgemeinschaft "Wirbelsäule" der Deutschen Gesellschaft für Unfallchirurgie. Unfallchirurg 104:583-600

21. Knop C, Fabian HF, Bastian L, Blauth M (2001) Late results of thoracolumbar fractures after posterior instrumentation and transpedicular bone grafting. Spine 26:88-99

22. Korovessis PG, Baikousis A, Stamatakis M (1997) Use of the Texas Scottish Rite Hospital instrumentation in the treatment of thoracolumbar injuries. Spine 22:882-888

23. Kostuik JP (1984) Anterior fixation for fractures of the thoracic and lumbar spine with or without neurologic involvement. Clin Orthop 189:103-115

24. Leferink VJM, Zimmerman KW, Veldhuis EFM, ten Vergert EM, ten Duis HJ (2001) Thoracolumbar spinal fractures: radiological results of transpedicular fixation combined with transpedicular cancellous bone graft and posterior fusion in 183 patients. Eur Spine J 10:517-523

25. Louis R (1977) Fractures instables du rachis. III. L'instabilite. A. Les theories de l'instabilite. Rev Chir Orthop.Reparatrice Appar Mot 63:423-425

26. Magerl F, Aebi M, Gertzbein SD, Harms J, Nazarian S (1994) A comprehensive classification of thoracic and lumbar injuries. Eur Spine J 3:184-201

27. Magerl FP (1984) Stabilization of the lower thoracic and lumbar spine with external skeletal fixation. Clin Orthop 189:125-141

28. Martijn A (1988) Thoracale en lumbale wervelfracturen: een evaluatie van conventionele röntgendiagnostiek. 1-139. Thesis Rijksuniversiteit Groningen.

29. McAfee PC, Yuan HA, Fredrickson BE, Lubicky JP (1983) The value of computed tomography in thoracolumbar fractures. An analysis of one hundred consecutive cases and a new classification. J Bone Joint Surg Am 65:461-473

30. Memmert M (1999) Ein Versuch, die Geschichte der Wirbelsäulenchirurgie zu umreissen. In: Memmert M, Memmert G (eds) Die Wirbelsäule in der Anschauung. Spurensuche in Kunst, Geschichte und Sprache. Springer-Verlag, Berlin Heidelberg, pp 247-270

31. Nicoll EA (1949) Fractures of the dorso-lumbar spine. J Bone Joint Surg Br 31:376-394

32. Olerud S, Karlstrom G, Sjostrom L (1988) Transpedicular fixation of thoracolumbar vertebral fractures. Clin Orthop 227:44-51

33. Oskam J, Kingma J, Klasen HJ (1994) The Groningen trauma study: injury patterns in a Dutch trauma centre. Eur J Emergency Med 1:167-172

34. Öner FC, van Gils AP, Dhert WJ, Verbout AJ (1999) MRI findings of thoracolumbar spine fractures: a categorisation based on MRI examinations of 100 fractures. Skeletal Radiol 28:433-443

35. Öner FC, van der Rijt RR, Ramos LM, Dhert WJ, Verbout AJ (1998) Changes in the disc space after fractures of the thoracolumbar spine. J Bone Joint Surg Br 80:833-839

36. Öner FC, van Gils APG, Faber JAJ, Dhert WJA, Verbout AJ (2002) Some complications of common treatment schemes of thoracolumbar spine fractures can be predicted with magnetic resonance imaging. Spine 27:629-636

37. Patel JC, Tepas JJ, Mollitt DL, Pieper P (2001) Pediatric cervical spine injuries: defining the disease. J Pediatr Surg 36:373-376

38. Richter AL (1828) Brüche und Verrenkungen der Knochen. Tafel XXX. Theodor Christ Friedr Enslin. Berlin

39. Roy-Camille R, Saillant G (1984) Les traumatismes du rachis sans complication neurologique. Int Orthop 8:155-162

40. Roy-Camille R, Saillant G, Berteaux D, Salgado V (1976) Osteosynthesis of thoraco-lumbar spine fractures with metal plates screwed through the vertebral pedicles. Reconstr Surg Traumat 15 :2-16

41. Shingu H, Ohama M, Ikata T, Katoh S, Akatsu T (1995) A nationwide epidemiological survey of spinal cord injuries in Japan from January 1990 to December 1992. Paraplegia 33:183-188

42. Trickey EL (1976) Injuries of the Spine. In: Wilson JN (ed) Watson-Jones Fractures and Joint Injuries. Churchill Livingstone, Edinburgh London and New York, pp 798-849

43. van der Sluis CK, Eisma WH, Groothoff JW, ten Duis HJ (1998) Long-term physical, psychological and social consequences of a fracture of the ankle. Injury 29:277-280

44. van der Sluis CK, Eisma WH, Groothoff JW, ten Duis HJ (1998) Long-term physical, psychological and social consequences of severe injuries. Injury 29:281-285

45. van der Sluis CK, Geertzen JH, Werkman HA, ten Duis HJ (1994) Epidemiologische gegevens van ernstig gewonden; een retrospectief onderzoek over de periode 1985-1989. Ned Tijdschr Geneeskd 138:2285-2290

46. van der Sluis CK, Kingma J, Eisma WH, ten Duis HJ (1997) Pediatric polytrauma: short-term and long-term outcomes. J Trauma 43:501-506

47. van der Sluis CK, Klasen HJ, Eisma WH, ten Duis HJ (1996) Major trauma in young and old: what is the difference? J Trauma 40:78-82

48. van der Sluis CK, Kucey DS, Brenneman FD, Hunter GA, Maggisano R, ten Duis HJ (1997) Long-term outcomes after upper limb arterial injuries. Can J Surg 40:265-270

49. van der Sluis CK, ten Duis HJ, Geertzen JH (1995) Multiple injuries: an overview of the outcome. J Trauma 38:681-686

50. van der Sluis CK, Timmer HW, Eisma WH, ten Duis HJ (1997) Outcome in elderly injured patients: injury severity versus host factors. Injury 28:588-592

51. Veldhuis EFM (1993) De behandeling van ernstig instabiele letsels van de thoracale en lumbale wervelkolom op het Strykerframe met halobitibiale tractie en Harringtonstabilisatie. Thesis Rijksuniversiteit Groningen. pp 1-135.

52. Versteegen GJ, Kingma J, Meijler WJ, ten Duis HJ (1998) Neck sprain in patients injured in car accidents: a retrospective study covering the period 1970-1994. Eur Spine J 7:195-200

53. Versteegen GJ, Kingma J, Meijler WJ, ten Duis HJ (1998) Neck sprain not arising from car accidents: a retrospective study covering 25 years. Eur Spine J 7:201-205

54. Versteegen GJ, Kingma J, Meijler WJ, ten Duis HJ (2000) Neck sprain after motor vehicle accidents in drivers and passengers. Eur Spine J 9:547-552

55. Versteegen GJ, Kingma J, ten Duis HJ (2001) Sprain of the neck in clinically treated patients in The Netherlands: an inventory of different categories of car accidents. Percept Mot Skills 92:655-658

56. Versteegen GJ, van Es FD, Kingma J, Meijler WJ, ten Duis HJ (2001) Applying the Quebec Task Force criteria as a frame of reference for studies of whiplash injuries. Injury 32:185-193

57. Weiss M (1975) Dynamic spine alloplasty (spring loading corrective devices) after fracture and spinal cord injury. Clin Orthop 112:150-158

58. Whitesides TEJ (1977) Traumatic kyphosis of the thoracolumbar spine. Clin Orthop 128: 78-92